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MECHANICAL | ORIGINAL ARTICLE

Analysis of Knee Joint

[1] P.Vinay Kumar and [2] Dr. Surya Kumar
[1] Department of Mechanical Engineering, *SRIIT*, Hyderabad.
[2] Department of Mechanical Engineering, *IIT, Hyderabad.*
[1] famevinay@yahoo.com and [2] ssurya@iith.ac.in

ABSTRACT

Knee joint is an important part of human body. Failure of knee joint may occur mainly because of surface to surface contact of femoral and tibial surfaces owing to the dry out of bursae fluid. The damaged surfaces must be replaced by artificial implants made of metals, ceramics, or composite materials. This process is known as total knee replacement. The failure of bearing component in knee implant is due to high stresses at the contact regions of femoral component and polyethylene insert causes wear and decreases the life of the implant. The stiffness of artificial implants is around 110 GPa to 210 GPa, while that of the human bone is around 17 GPa. This increases the stress shielding effect. To reduce stress shielding effect an implant material should have the stiffness value nearer to human bone. This reduces the effect of stress shielding between the bone and implant.

Keywords: Knee Joint, Femoral and Tibial component, Stress shielding effect

I. INTRODUCTION

Rapid Prototyping (RP), also known as Additive Manufacturing (AM), is a totally automatic process of manufacturing objects directly from their CAD models. With the help of RP technology 3D models can be easily generated a layer by layer deposition process. The 3D CAD data is sliced into 2D layers and realized one layer at a time, making it simple to construct a 3D model and manufacture. A study conducted by Milan *et al.* [1] in 2011 reported in that about 800,000 knee joint replacements are carried out per year worldwide. Nagarjan et al. [2] studied different rapid prototyping technologies used in medical applications. Gibson et al. [3] did some case studies on the applications of RP technology in medicine. Jeng-Nan lee et al. [4] studied the application of Rapid Prototyping technology and multi axis machining for fabrication of femoral component of the knee prosthesis. Juan Felipe et al. [5] designed and manufactured a skull implant by Titanium alloy.Milan et al. [1] studied on the production of medical implants by using rapid prototyping technology and investment casting technology. Niinomi et al. [10] studied on preventing stress shielding between the implant and the bone. B.R Levine et al [11] studied on clinical performance of porous tantalum in orthopaedic surgery which is having a young's modulus of 3 Gpa having high volumetric porosity of 70-80% and excellent biocompatibility.

II. MECHANICAL PROPERTIES OF HUMAN BONE

Human bone is an isentropic, heterogeneous and viscoelastic material which should withstand the weight of the body and tabilize the body. The mechanical properties of the bone are tabulated in Table 1.

Property	Longitudinal	Transverse
Young's dulus (MPa)	17,000	11,500
Ultimate tensile strength (MPa)	133	51
Ultimate compressive strength (MPa)	193	133
Ultimate strain	3.1%	0.7%

Table 1: Mechanical properties of bone [8]

III. PROBLEM DEFINITION

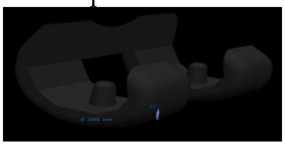
The failure of knee joint replacement is because of wear between the knee joint components (Femoral component, PE insert and Tibial Tray). The early detection of contact stresses in the components prevents wear and increases the life of knee joint replacement. Tomasoet, al [9e] conducted

experiments on knee joint component to find the contact stresses at different stages of gait cycle in between Femorel component, Tibial Tray and PE insert. The femoral component and Tibial Tray is made of Cobalt chromium and bearing component is made of Ultra High Molecular Weight Polyethylene. Vertical load is applied on the model at various flexion angles from $15^0 - 60^0$ as follows:

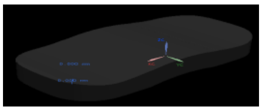
Flexion angle (^{0})	Load applied (N)
15	2200
45	3200
60	2800

CAD model of Knee Joint

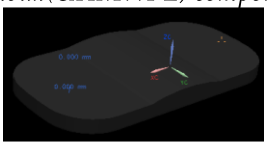
3D geometrical model of knee joint implant is designed using Unigraphics NX7.5 software. The dimensions of femoral component are taken from the femur bone. The geometrical model of femoral component, tibial components is shown in the Fig 1.



a) Femoral component



b) *Tibial(UHMWPE) component*



c) Tibial baseplate component

Figure 1: Components of Knee joint implant

The assembly of knee joint implant consists of femoral component; tibial UHMWPE component and tibial base plate are shown in the Figure 2.

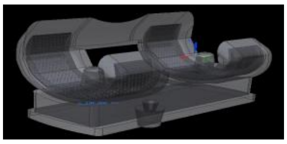


Figure 2: Assembly of improved knee implant

Analysis of Knee Joint; Mesh development:

The knee joint model is meshed with h-adaptive technique, using TET10 element, shown in the Fig. 3

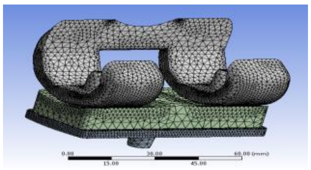


Figure 3: Mesh of Model 1knee joint implants

Materials and their properties:

Materials: The materials used in knee joint replacement surgery must have certain properties like:

- Biocompatibility,
- Non-corrosive,
- Non-toxic and
- Anti-allergic.

The following are some materials which used in knee joint implants by researchers and medical practioners:

1. Cobalt chromium alloy (CoCrMo)
2. Titanium alloy's
i. Ti-6Al-4V
ii. Ti-29Nb-13Ta-4.6Zr also known as TNTZ etc.
3. Stainless steel 316L
4. Ultra High Molecular Weight Polyethylene (UHMWPE)
5. Porous Tantalum

Properties:

The properties of materials are tabulated in Table 2

Material	Density (Kg/m3)	Youngs modulus (Gpa)	Poissons ratio	Tensile Yield strength (Mpa)	Ultimate tensile strength (Mpa)
CoCr	7990	200	0.3	560	1000
Ti6Al4V	4430	113.8	0.36	880	950
TNTZ	6075	50	0.36	800	820
SS 316L	7990	193	0.3	290	558
UHMWPE	926	0.69	0.45	21	48
Tantalum	16650	3.5	0.34	51	110

IV. RESULTS & DISCUSSION

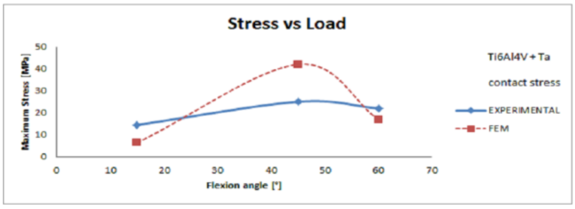
The knee joint implant is made of titanium alloy, to reduce the stress shielding effect at the implant. Finite Element Analysis is performed to determine the contact stresses between Femoral component & PE insert and the stress shielding effect in between

the bone and the Femoral component. In this process, two cases were studied.

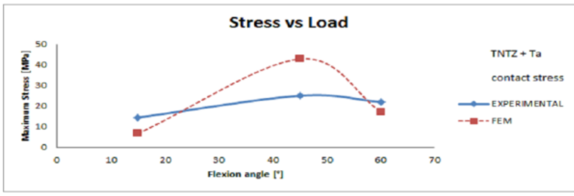
Case 1: Implant made of Titanium alloy (Ti-6Al-4V) and Tantalum.

Case 2: Implant made of Titanium alloy Titanium β-alloy (TNTZ) and Tantalum

The contact stresses between Femoral component and PE insert for above two cases are obtained at different flexion angles and are compared with the experimental results [9]. From the results it is found that, the contact stresses are less compared to the experimental results. This proves that the knee joint model is best and increases life of the knee joint implant. This indicates reduction in stress shielding effect and bone resorption between the implant and the bone.

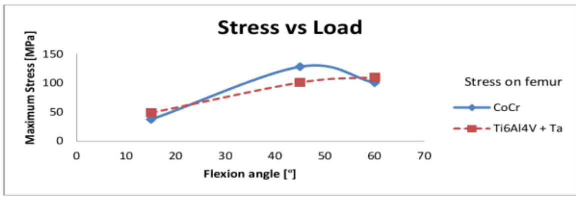


a) Ti6Al4V + Ta

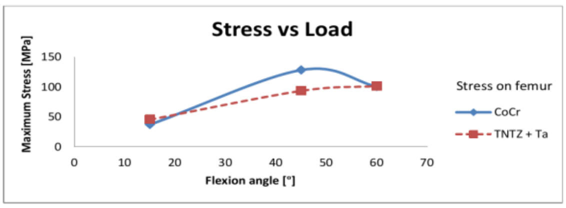


b) Ti6Al4V + Ta

Figure 4: Comparison of contact stresses between FC and PE insert for Experiment and FEM



a) Cocr and Ti6Al4V+Ta



b) Cocr and Ti6Al4V+Ta

Figure 5: Comparison of contact stresses on Femoral component

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